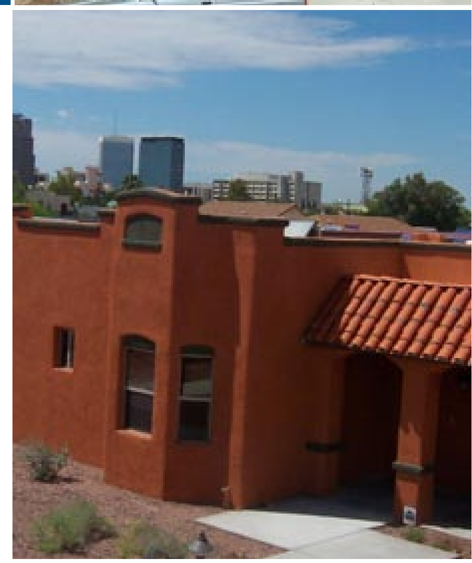
Building America Best Practices Series

High-Performance Home Technologies: Solar Thermal & Photovoltaic Systems

Chapter 4. Photovoltaic Power Generation



Homes with PV systems typically fit in with their neighbors.

Enjoying the dappled light filtering through a tree may be as close to understanding the physics of photovoltaic (PV) systems as most consumers will get. Tree leaves absorb solar energy for photosynthesis. Like leaves on a tree, PV systems produce energy from the sun. Even though the PV process is a phenomenal scientific breakthrough, the technology and its application are straightforward. Innovators around the world have taken much of the guesswork out of PVs, and research continues to improve efficiency, cost, and style. PVs are electric generators and must be properly designed and installed, but the technology is readily usable and effective.

Builders' Brief

- PV cells, frames, wiring, and mounting hardware have all advanced to provide integrated systems that can be barely discernable on a house.
- Inverter reliability is improving with 10-year warranties available.
- Net metering allows consumers to receive credit for the power they produce that exceeds the amount they use.
- The National Electrical Code provides detailed guidance for PV installation.
- Solar PV installers can be certified by NABCEP; find out if they are or what their plans are for becoming certified.
- Incorporate solar information into the homeowners manuals that you provide.
- Select packaged systems where possible for the benefits of pre-engineering.
- Insist that solar installers meet with other trades to work out equipment compatibility, supply, and installation issues.
- Quality assurance inspections and tests will ensure that PV systems are properly working.

Installers' Brief

- Use specialized knowledge to educate builders and other trades. New construction provides an opportunity to optimize the equipment and installation process.
- Take advantage of the bulk purchase opportunities afforded by production building.
- Work with site supervisors, roofers, plumbers, and others to determine the best installation sequence and schedule, what materials to provide, and how to avoid shading from vents and other roof penetrations.
- Confirm solar exposure before mounting hardware on the roof.
- Provide quality assurance inspections.
- Many problems are related to craftsmanship – use quality assurance techniques to avoid problems.
- Work with the builder to develop inspection protocols.
- Correct installation and craftsmanship problems immediately.

(top) Reach for the sky!

(bottom) PV cells have grown more diverse and efficient. This photo was taken at the NREL outdoor test facility and shows both mono- and multi-crystalline cells.

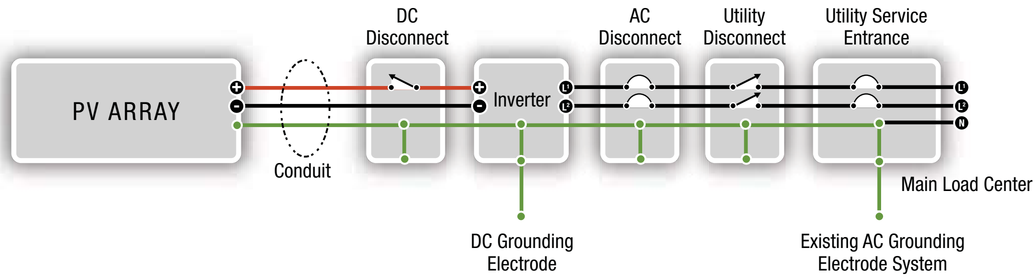
Recent Innovations: Modules are on the market that are made to replace or supplement roofing components. These systems are described later in this chapter and are called building integrated PV.

PV Building Blocks – The Basics

Every house that is connected to an electric utility has a main service panel, an electrical meter and a line to the grid. Power flows from the grid through the meter to the panel where it is distributed through the wires in the house. When PV or some other form of on-site power generation is added, additional power from that source will also flow to the Main Service Panel to be distributed throughout the house. Simple grid-tied PV systems have similar additional components that will connect between the PV and the main service panel.

A PV installation is an electrical project, and usually a roofing project. Much work has been done with proper procedures, National Electrical Code (NEC) applications, and proposed NEC changes. A good source of information on these topics is www.nmsu.edu/~tdi/. One suggested publication available on that web site is *Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices* (Wiles 2005). References in this chapter will often refer to portions of the NEC as described in the *NEC 2005 Handbook* published by the National Fire Protection Association (NFPA 2005). The North American Board of Certified Energy Practitioners (NABCEP) certifies PV installers. The NABCEP library is a good source of reference material (www.NABCEP.org).

Residential PV System



Schematic diagram of a typical residential PV system. *Adapted from Wiles 2006a.*

Photovoltaic Arrays

PV systems are made with semiconductors like the materials used for integrated circuits in computers. These semiconductors convert sunlight into direct current (DC) power, just like the electricity produced by batteries.

The wafers used to make the semiconductors are created from refined silicon (an element found in quartz and among the most common elements on earth). Traditionally PV cells have been made from waste silicon from the computer industry. Now that PV is becoming a larger market share, more silicon production facilities are coming online.

The most basic part of many PV systems is the Cell. A cell is typically a small silicon square (or rounded off square). Each cell generates about 0.5V. In comparison most small batteries like AAA or watch batteries are 1.5V. Cells are combined to create a PV Module or Panel.

A module is a standalone piece that is enclosed between sheets of tempered glass or plastic to protect the cells. PV modules should be listed to UL Standard 1703. Modules are installed in a set called a PV array.

An array is designed to generate a specific amount of energy. There can be one, a few, or very many modules in an array.

PV cells are one of three types: mono-crystalline, multi-crystalline, or amorphous (thin-film).

- **Mono-crystalline (or Single-crystalline)** cells are grown from a single silicon wafer. They are the most efficient type of PV cell. Because of the way they are grown, mono-crystalline cells are rounded. An early industry innovation was

Talking Shop – Staying Current

Photovoltaics are electric generators. The name is taken from a combination of light (photo) and electric force (volt). Electric basics apply and here are some of the basic electrical terms. Mathematically, the first three terms are related: **Volts = Watts/Amps**

A **volt** is the unit of measurement of force in an electrical circuit that causes current to flow. It is electrical "pressure" analogous to water pressure. Volt is abbreviated V and sometimes E. Voltage will always cause current to flow from a place of higher voltage (higher pressure) to one of lower voltage. One volt is the amount of force needed to produce one ampere of current in a circuit having a total resistance of one ohm.

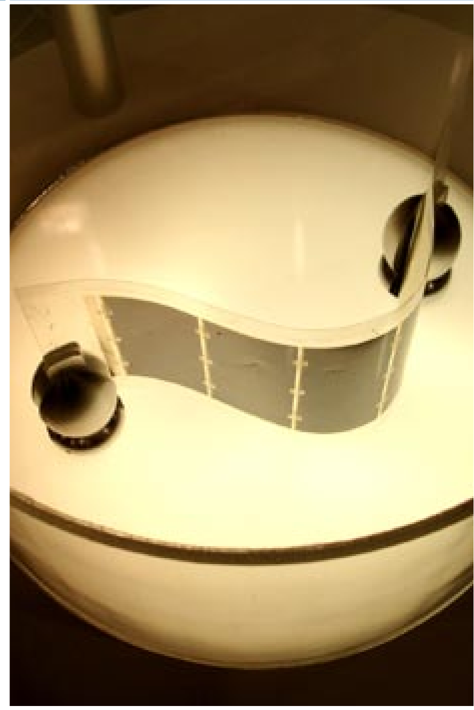
Amperes or amps refer to the rate of current – or electron flow – through a wire. Amps are abbreviated A or sometimes I (for intensity). In terms of water, amps are similar to gallons per minute.

Watts show the rate at which electrical energy is produced (or used). Watts are the power. Watts are abbreviated W. We frequently see the abbreviation kW for kilo Watts – one thousand Watts. A Watt is an amount of electrical power that is equal to one Amp under the pressure of one volt.

Resistance is a measure of the degree to which an object opposes the passage of electrical current. The resistance of a wire depends on the material it's made of, the thickness (cross section) of the wire, the length the current has to travel on the wire and the temperature of the wire. Resistance is abbreviated R and measured in ohms or Ω.

Direct Current is the type of current produced by generators such as batteries or PV modules. It flows in one direction and produces little variation in voltage. Many household items are run on direct current – flashlights, computers, MP3 players, cameras.

Alternating Current is current that alternates between negative voltage and positive voltage with a regular cycle. Almost all electricity produced by U.S. electric utilities is AC and alternates 60 times a second (60 Hertz). Most large household appliances run on alternating current.



This display of amorphous (thin) PV film shows its flexibility.

to trim the cell sides to pack more cells closer together in modules.

- **Multi-Crystalline (or poly-crystalline)** cells are made up of variously oriented, small individual crystals that have been cast in a block. They range in color from bright blue to black. With their shape and crystalline structure, the multi-crystalline cells with small crystals resemble dark granite countertops. Cells made with larger crystals resemble the structure of oriented strand board, but are glossier. Multi-crystalline cells are rectangular and closely butted into modules. Their larger surface area and denser packaging make up for the small difference in efficiency between multi-crystalline and mono-crystalline cells, leaving them essentially equivalent in generating efficiency.
- **Amorphous (or thin-film)** modules are made by depositing a very thin film of semiconductor onto a substrate (glass or plastic). This technology does not use individual crystals and the substrate can be flexible. These modules are approximately half as efficient as the mono- or multi-crystalline modules, but also currently cost about half as much.

Recent Innovation: Thin film is the newest of the PV technologies and should help reduce manufacturing costs as well as materials costs for future products. Some of today's thin film products are described later in this chapter in the section *BIPV Systems: Putting the Pieces Together*.

Residential inverter with backup batteries stored inside the box. *Photo courtesy of Leif Juell, Alternative Power Enterprises, Inc.*

The Grid

For most homes, the source of power is the grid. The grid is a common name for the electric utility companies' transmission and distribution systems (wires and substations) that link power plants to customers through high power transmission line service. The power on this line is AC. Most PV installed on new homes will be grid-tied (also known as Utility-interactive) – or attached directly to the grid through the homeowner's electrical service.

Grid Tied and Battery Backup

Standalone PV systems use special inverters and batteries to store power that is generated by the PV system. This adds major cost and design complexity to a PV system. Unless there is a very specific regular need for battery backup, or a home is being built on a site more than half a mile away from any electric utility, Building America recommends grid-tied systems. Essentially, grid-tied systems use the grid as a battery. These systems provide renewable resources to the homeowner and to the utility buying the excess power. However, when

The Bottom Line

"Even based on a PV system cost of $18,000 to $20,000 for a PV system bundled with energy efficiency improvements, if that cost is included in a 30-year mortgage with a 6.5% mortgage rate, the annual utility bill savings is usually greater than the annual increase in mortgage cost. When we compared the incremental mortgage cost to annual energy savings, we showed a positive cash flow."

David Springer, Davis Energy Group

Net Metering – Getting Credit For the Sunshine

In most states if the homeowner's PV array produces more power than the homeowner is using, the extra power is sent back to the grid and the homeowner will be credited by the local utility for that power. This credit for excess power is called Net Metering. At least 40 states allow net metering.

How does net metering get set up?
Any net metering will require special arrangements with your local utility. Forms will need to be filed with the utility to start a net-metering account. Not all utility meters are capable of net metering; in some cases special meters will replace the standard meter, in other cases an additional meter will need to be installed to show the flow of the energy going to the utility. Your solar installer should be familiar with the forms and hardware requirements of the utility.

How much power can I send back?
Each state has different requirements and allows different sized systems to qualify for net metering. In some states only major utilities are required to accept net metering. Some states only require the utilities to accept a limited amount of energy back from consumers. Some utilities offer net metering even when it is not required by the state.

How much credit will the utility give?
The amount of money paid for the energy varies widely: from the price the utility pays to make energy themselves to the highest price a consumer might pay based on Time of Use. In most states credits are earned each month based on kWh and are applied to the next bill.

What happens at the end of the year?
Usually there is some kind of "true up" at the end of the year or billing period. The "year" is either defined as the end of the calendar year – December 31, or the year since you contracted with the utility. In California, at the end of the year since you connected to the grid, any extra credits earned go back to the utility. In Colorado, at the end of the calendar year, the utility must pay the customer for any extra credits at the utility's average hourly incremental cost for the year.

Check www.dsireusa.org and www.irecusa.org/connect/index.html for the latest information for your state and pointers to your local utility's net metering website.

Grid tied inverters. One mounted on a California garage wall, the other in a Maryland basement. The remote display can be placed anywhere in the house for consumers to keep tabs on power production. Web-based services are also available to monitor PV system performance. Builders need to plan ahead to save space for the inverter and breakers.

the grid is not functioning (there is a blackout), the grid-tied PV system does not provide power to the house. Facilities that offer emergency services during disasters are good candidates for battery backup systems. Candidates would include clinics, fire stations, police departments, and dispatch facilities.

Inverter

In many respects the inverter is the most complex component in a PV system. An inverter takes DC current and shapes it into AC current. With a grid-tied system the inverter "listens" to the AC current being delivered to the house and "echoes" the sine wave shape and timing of the wave of power being delivered. This way the PV power that is received by the house looks just like grid power. When more power is generated than is needed by the house, the extra power will blend seamlessly back into the grid for use by other houses or electrical loads in the utility system.

If the utility goes down and there is no power coming from the grid, the inverter will turn off since there is nothing to echo. This feature helps to ensure the safety of linemen working to fix the grid. Unless there are batteries involved in the PV system, no power will be available to the household when the grid is down. This may be surprising to homeowners, since their system will be capable of generating power, but without batteries and a special inverter to switch to the battery back up no solar power will be available to use until the grid comes back up and the system automatically restarts.

As the most complex part of the system, the inverter literally takes the heat of converting DC to AC power. Like other electronic equipment, inverters must dissipate heat. Inverters may be designed for either indoor or outdoor installations, but indoor installations are more common and provide better protection. It is important to plan on space for the inverter to be located near the main electrical panel. Inverter innovation has made large technical strides in the last 10 years. Inverters are becoming more efficient, durable, and versatile, and some can handle multiple strings of PV modules with varying voltages.

Grid-tied inverters should meet UL Standard 1741.

Recent Innovations: Inverters with 10 year warranties are now available in the U.S. European style non-grounded inverters are allowed by the 2006 NEC (NEC 690.35) code, although not all jurisdictions have adopted the most recent versions of the code. Remote sensors allow consumers to read inverter output anywhere in their house.

Photos of finished (top left) and roughed-in exterior junction boxes (right) offer an example of how roof flashing attaches to these PV system components.

(bottom left) Connectors

Recent Innovations: "Plug and play" cable systems have made wiring faster and more durable. These cables are made to snap together, much like stereo or computer component cables have worked for years. Some manufacturers have also made grounding wires easier to install by providing pre-mounted cables. If the wires are accessible after the modules are installed, the connectors must have a mechanical connection to prevent accidental opening. Accessible junction boxes are required if PV module placement makes wire connections inaccessible (NEC 690.34).

Wires and Connections

Wire sizing is very important as a safety feature of PV systems. The photovoltaic contractor, electrician, or engineer must properly size the array, the wire, and the inverter. The correct type of wire will have to be chosen as well. Here is some of the information that should be considered for wire sizing:

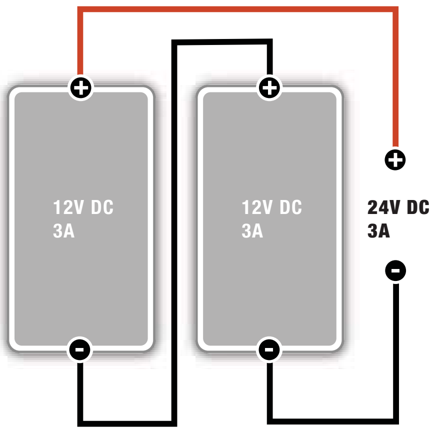
The size of wire needed for a PV installation depends on the amperage the wire needs to carry and the distance it must travel. There are three things that can affect wire size: voltage, temperature, and wire type. For the same amount of wattage, if you can raise the voltage on a wire, the number of amps will decrease and the wire size can be reduced. Wire length affects voltage. The longer the wire, the more voltage will be "lost" along the way.

In other words, the higher the pressure, the less flow you need to create the same power (Amps =Watts/Volts). This is why the electric utilities transmit power across the U.S. at such high voltages; otherwise the cables would be huge. With the high prices of copper, aluminum, and conduit, properly sized wire is a huge cost savings. For new homes, PV systems with batteries are restricted to no more than 48V, unless energized parts are not accessible during routine battery maintenance (NEC 690.71(B)(1). But grid-tied systems without batteries are almost always higher voltage and can go up to 600V while still meeting the National Electrical Code (NEC 690.7C).

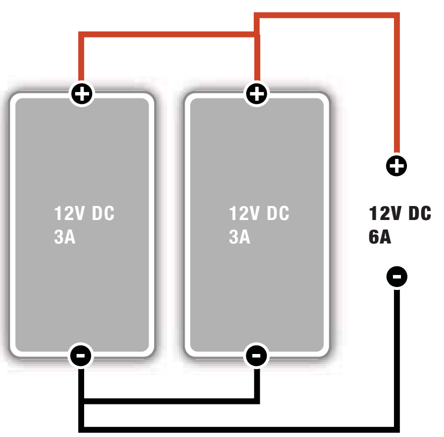
The most common types of wire are copper and aluminum. Copper has a greater conductivity than aluminum and can carry more current than an aluminum wire of the same size. It is also more expensive. Aluminum is less reliable in smaller gauges and is not permitted by NEC for interior home wiring. Another variable of wire type is insulation. The insulation covering of a wire can protect the wire from water, heat, or sunlight. Depending on the coverings available, conduit may be required to protect the wire. Exposed wire should be water and sunlight resistant. Smaller wire will require smaller conduit.

PV arrays are made up of PV modules connected together. There are two ways to connect those modules—in series and in parallel.

- In series, voltages add up but amperage stays the same. Two 12V at 3A modules wired in series will give 24V at 3A. In essence, the two modules run one after the other and the "pressures" add up while the "rate of flow" stays the same.



- In parallel, voltages stay the same but amperages add up. The same two 12V at 3A modules wired in parallel will produce 12V at 6A. The two modules effectively run side by side, and the "pressures" are even, but the "rates of flow" at the end add up.



- A row of modules wired in series is known as a string. Strings of modules can be paralleled together in junction boxes (combination boxes) nearby (before the inverter) to reduce the number of wires that are connected to the house or each string can have its own inverter and be combined on the AC side of the system (after the inverters).

Wire color coding is a safety issue and a code issue. Wire colors on the DC side and AC side are the same.

- The grounded conductor or neutral must be white or gray (or marked with those colors). Remember this line can carry power.
- The equipment ground must be green, green with yellow stripes, or bare.
- The hot-ungrounded conductor may be any other color, usually red or black.

Overcurrent Protection

NEC requires that all ungrounded conductors in a PV system be protected by overcurrent devices. These devices protect the wire from electrical current that exceeds the wire's amperage limits (ampacity). It is possible to have excess electrical current on both the DC side as well as the AC side. Circuit breakers or fuses that are used on the DC side must be UL listed and DC rated for the application. These breakers or fuses are not intended to protect equipment from damage, but to protect the wire from overheating and potentially causing fires. Code specifies the correct sizes of overcurrent protection based on the ampacity of the wire used, its insulating material, and the temperature.

Disconnects

All homes require at least one disconnect. Electric power from the utility enters a home through either an overhead or underground feeder. Before this feeder gets into the house, it usually first goes through a billing kilowatt-hour meter and then the service entrance disconnect. In many jurisdictions, the main disconnect may be immediately inside the home at the point of first penetration as allowed by the NEC (Section 230). A growing number of jurisdictions require that a service entrance disconnect must be located on the outside of the house. In all cases this disconnect must be readily accessible. These requirements were established many years ago to allow fire response personnel to quickly shut off power to a building so that firefighters can safely enter the building and cut holes in walls, ceilings and roofs in life threatening situations.

Some BIPV systems tie into a junction box that was installed during the rough-in stage of contruction.

Exterior disconnect.

Recent Innovations: As of NEC 2005, ungrounded systems are permitted (not required) in the United States. (NEC 690.35) PV installations in Europe and Japan have been ungrounded for decades, but this is new technology for North America. Allowing this technology will bring smaller, lighter, less expensive inverters from Europe. The inverters don't need internal isolation transformers so they weigh less. This change requires the use of listed PV wire technology—double insulated single conductor wires. Use of ungrounded systems will require training on the installer/electrician side and the inspector side of solar installations.

In homes with PV systems, the NEC (section 690.14) requires supplementary disconnects in addition to the main feeder disconnect. One required PV disconnect is between the PV arrays and the inverter. If the attic is readily accessible with permanent stairs, and the PV is on the roof, this disconnect may be near the point where the output wire from the PV array first enters the house. Or, the disconnect may be right next to the inverter if the DC conductors are in a metallic raceway or pre-assembled metal clad cable. Some inverters have incorporated a disconnect switch into a box attached to the inverter.

The NEC requires that each piece of PV equipment have disconnect switches allowing service providers to disconnect the equipment from all sources of power. For example, an inverter must have a disconnect between it and the array, and between the inverter and the panel. The disconnects may be circuit breakers or switches (Section 690.17). DC-rated switches are expensive; therefore, the ready availability of moderately priced DC-rated circuit breakers with ratings up to 125 volts and 110 amps may be a good choice for use in all 12-, 24-, and 48-volt systems. When properly located and used within their approved ratings, circuit breakers can serve as both the disconnect and an overcurrent device.

In grid-tied systems, the number of disconnects depends on the complexity of the system. In a simple system there would be disconnects on both sides of the inverter, in addition to the main feed disconnect required on all houses. In more complex systems, there may be disconnect switches for each string of arrays, sub-array disconnects, main PV disconnects for each inverter, sub-panel and AC disconnect (you can only have one AC disconnect per utility service). If there are multiple inverters they must be combined in a dedicated subpanel that feeds one AC disconnect) and a main feed AC disconnect.

Disconnect switches must be rated to carry appropriate levels of current and have appropriate voltage and interrupt ratings (NEC Section 110.3(B)).

Recent Innovation: Modern inverters may also include integrated DC disconnect switches. In these systems, a separate DC side disconnect may not be required.

Main Electrical Panel

Usually power from the inverter is pushed (backfed) into the main service panel of a house through a circuit breaker. The number of amps that can be pushed through is dependent on the original size of the electrical panel (load center). The sum of the rating of all breakers supplying power to a panel must not exceed 120% of the panel rating. The backfed PV breakers and the main breaker supply power to the panel (NEC 690.64B). For example a panel rated at 100A with a 100A main breaker can have 20A additional backfed from a PV system.

If the system being installed is larger than 20% of the panel rating, there are other ways to connect to the main panel, but these require specific electrical design.

Grounding

NEC 2005 requires any PV system carrying more than 50V to be grounded (NEC 690.41), unless specific requirements are met (found at NEC 690.35). These types of systems are common in other countries. Also, PV systems must have their equipment grounded—even at only 12V (NEC 690.43). Grounding limits problems due to lightning and other line surges and makes the system safer for people working on and around the system.

There are two types of grounding—equipment grounding and system grounding.

- Equipment grounding is done to prevent shock when touching metal parts that don't usually carry electricity (for example the frames of the modules, the junction boxes, appliances). If any of the exposed metal is touched by a live wire the metal becomes electrified as well – this is called a ground fault. A person who touches this live part will complete the circuit and be shocked. To solve this problem all exposed metal parts are wired to the grounding electrode. The grounding system must connect every exposed non-current-carrying part of the installation to ground. The equipment ground wire is either green, green with yellow stripes, or bare.

- System grounding takes one current-carrying conductor and attaches it to ground. On the DC side that is the negative or positive (depending on the inverter and module specifications) conductor (white or gray wire); on the AC side it's the neutral conductor (white or gray wire). The closer the grounding connection can be to the PV source the better the protection from surges due to lightning.
- When servicing you must be able to remove a module without breaking the system ground circuit. Some modules on the market are not compliant with this code issue. Ensure that modules for your job meet this code requirement.

BIPV Systems: A New Way of Putting the Pieces Together

Fundamentally, all PV systems have similar components and work in similar ways. At the beginning of this chapter was a diagram of a generic system. Although systems work in similar ways, they do have different architectural styles and engineering methods for how they are integrated with a house in order to take advantage of the unique characteristics of module materials.

Even though their use is more widespread, PV systems have become much more difficult to spot on rooftops. Building integrated systems are literally built into the building and have the same profile as nearby materials.

Most PV systems still mount on racks, but many of these systems have such a low profile they appear to be thin skylights. A review of products available in the U.S. can be found in the November 2005 issue of *Energy Design Update* (EDU 2005). Mounting systems that place PV arrays very close to the roof surface, but not actually integrated into the roof, are described in Chapter 6: Solar System Mounts. More traditional rack systems are also described.

BIPV stands for Building Integrated Photovoltaics. These systems represent a major innovation in incorporating PV into residential architecture. BIPV systems are PV arrays that also serve as an integral part of the building. The PV arrays usually replace other parts of the shell – typically roofing material.

Recent Innovations: Module manufacturers are providing grounding screws and pre-installing cables to ease installation.

Recent Innovations: Building Integrated and direct mount systems hide most hardware, are difficult to spot, and use the array to cover most roof penetrations, helping to keep penetrations out of the direct weather.

Standard Fire Ratings for Roof Coverings – UL 790

Three classes of fire exposure are described:

Class A roof coverings are effective against severe fire test exposures. Under such exposures, roof coverings of this class afford a high degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands (burning objects).

Class B roof coverings are effective against moderate fire test exposures. Under such exposures, roof coverings of this class afford a moderate degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.

Class C roof coverings are effective against light fire test exposures. Under such exposures, roof coverings of this class afford a light degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.

(photo series) Cement tile system step-by-step installation

Photo numbers correspond to paragraph numbers. Not all paragraphs have a corresponding photo.

Here are some of the currently available cement tile type PV systems:

- EnergyTile – BP Solar
- GEPV-055 – GE Energy
- MyGen | Meridian – Kyocera
- ND-62RU1 – Sharp Solar
- SolarSave – Open Energy Corporation
- SunSlates – Atlantis
- SunPower

Cement Tile Systems

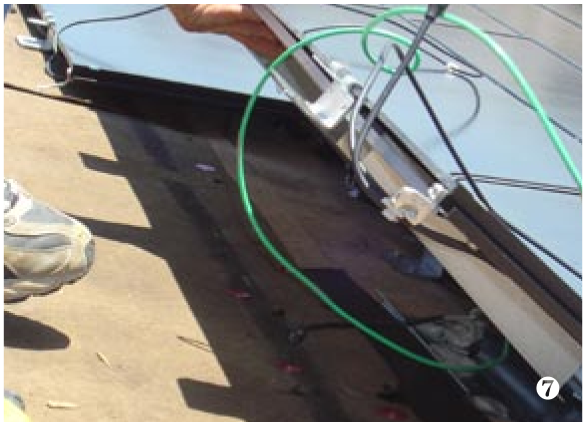
Perhaps the most popular integrated system in the U.S. is made up of PV modules that are sized and mounted to replace cement tiles. The most common systems use mono- or poly-crystalline cells. The PV tiles are installed on roofs in a way that blends in with cement tiles. The PV tiles follow the contour of the roof in exactly the same way as do the cement tiles. Electrical connections are made between each tile. In some cases a single module will replace a set of three or four tiles, reducing the number of connections. Many of these tiles, when installed according to manufacturer specifications, are Class A fire resistant.

The PV arrays weigh less than the cement tiles they replace. But the roof must be engineered for the correct weight and any supporting structure is done in advance. Since these products are replacing roofing material and are the first line of defense against the elements, they should be compliant with local and national roofing requirements. Some BIPV products have been tested by UL as a Listed roofing material under UL 790 (Class A Fire) and UL 997 (110 wind rating), as well as UL 1703 (PV Module). In addition the ICC recently established acceptance criteria to provide guidance for the evaluation of BIPV roof panels (ICC 2006). Builders should ask installers or other suppliers to confirm that BIPV systems meet these standards.

Each manufacturer has specific requirements for its product. One product selected as an example is the SunPower SunTile. These PV tiles are placed on top of an underlayment that covers the roof deck. The underlayment helps to provide Class A fire rating. The following text and photos describe the installation sequence for this product.

Photo numbers correspond to paragraph numbers. Not all paragraphs have a corresponding photo.

1. After framing but before insulation and sheetrock are installed the house is prewired for the PV array. Metallic armored cable is run from a loose junction box placed near the roof to the point where the inverter will be installed. Rough-in boxes are installed as end points for the cable. The inverter is installed and lines are run to the shutoff on the AC side and to the main panel. This product is lighter than the tiles replaced, so no extra structural support is needed.



(photo series, continued) Cement tile system step-by-step installation

❷ Roofers install cement tiles in all areas except where the PV array will go. The PV crew installs underlayment over the roofing felt to achieve a Class A fire rating.

❸ Before installing any PV modules, the crew checks for proper solar exposure. In this case the crew determined that the house next door would shade the system as originally designed. The crew adjusted by moving the location for the array farther up the roof. This adjustment required removing some of the cement tile battens near the ridge and installing a new course of cement tiles at the base of the array.

❹ Brackets are installed for the first run of PV tiles. All brackets are sealed to the underlayment with butyl tape.

❺ PV tiles are installed row by row. Each row is tested for proper power production as the PV tiles are installed. The entire array is grounded through the inverter back to the main panel. Plug and play cables and connectors wire together the modules.

❻ Any penetration left over from removing obstructive nails or a screw that did not seat or for any other reason is sealed with caulk.

❼ A tube that is combined with flashing and a seal guides the positive, negative, and ground wires through the roof. An additional seal is provided with caulking. The last PV tile covers the wire receiver.

❽ The junction box that was left hanging loose at the top end of the interior wiring is now attached at the point where the wire receiver penetrates the decking. The PV wires are hot as soon as the array is installed, so wires from the PV should not be wired into the interior wires until the system is ready to accept the electric current.

❾ Wiring can be connected to the inverter AC disconnect and the main panel. The AC disconnect is located outside within sight of the main service panel for access by utility and emergency crews.

❿ An example of the finished product is the model home at Grupe's Carsten Crossing in Rocklin, California.

"When Premier Gardens' homeowners started moving into their homes in fall 2004, their September energy bills averaged $20 while their neighbors were paying around $70. The homes are nearly identical in size and price but the Premier Homes sport advanced energy-saving features and a 2.2-kWh photovoltaic tile system on every roof."

According to ConSol, a U.S. Department of Energy Building America Team Partner.

Photo courtesy of Decker Homes.

Photo courtesy of Decker Homes.

(photo series) Metal standing seam roof laminate systems step-by-step installation.

(above) Photo courtesy of Leif Juell, Alternative Power Enterprises, Inc.

Photo numbers correspond to paragraph numbers. Not all paragraphs have a corresponding photo.

Thin Film PV Laminate for Raised Seam Metal Roofs

One interesting place to put solar is on a metal standing seam roof. This laminate on soft plastic rolls out to fit between the seams. While this does not replace the metal on the roof, it is directly attached with glue during installation of the roof. The electrical connections are made under the roof ridge (an easily accessible place for maintenance). The systems are easy to install with no additional structural support required. The system is produced by Uni-Solar Laminates – Uni-Solar Ovionics.

Examples of installations of metal standing seam roof laminate systems follow. Photo numbers correspond to paragraph numbers. Not all paragraphs have a corresponding photo.

1. After framing but before insulation and sheetrock are installed the house is pre-wired for the PV array. Metallic armored cable is run from a loose junction box placed near the roof to the point where the inverter will be installed. Rough-in boxes are installed as end points for the cable. The inverter is installed and lines are run to the shutoff on the AC side and to the main panel. No extra structural support is needed for this product. Preparation may include providing conduit races through the peak to run wires.
2. The metal roof must have steel pans that are at least 16" wide. They must be flat surfaced with no pencil beading or decorative stippling.
3. The pans must be cleaned well to the manufacturer's specifications.
4. The laminate is installed onto the pans before the pans are installed on the roof. The laminate comes in pre-cut rolls and comes with the glue already adhered to one side. Peel the protective covering and adhere the laminate to the pan. Make sure there are no bubbles. This job could be completed in a shop to maintain a clean surface and to keep materials out of the weather.
5. Install the pans on the roof normally with the wires facing the peak.
6. There are no penetrations in the pans with this type of solar array, reducing the possibility of leaks.
7. The wires are connected along the ridge of the roof and covered later by the ridge cap. The

Photo courtesy of Leif Juell, Alternative Power Enterprises, Inc.

(top) Photo courtesy of Decker Homes.
(bottom) Photo courtesy of Leif Juell, Alternative Power Enterprises, Inc.

(photo series) Metal standing seam roof laminate systems step-by-step installation. *Photo courtesy of Decker Homes.*

NEC requires that wires penetrating the roof be inside metal conduit.

8 PV wires are hot as soon as the array is installed, so wires from the PV should not be wired into the interior wires until the system is ready to accept the electric current.

9 Wiring can be connected to the inverter AC disconnect and the main panel. In this example, the AC disconnect is located outside for access by utility and emergency crews.

10 An example of a finished home using Uni-Solar Laminates.

Non-Roof BIPV

South facing walls can be covered in PV vertically or can be slanted to act as window shading and PV at the same time.

Thin-film PV can be set between two sheets of tempered glass to make a filtered window or filtered skylight that also collects power. This runs about three times more expensive than regular PV but can make a powerful architectural statement.

Mono- or poly-crystalline PV can also be set between sheets of glass to create a dappled effect, blocking the majority of sunlight to make electricity, but allowing shaded light through. This reduces solar gain to the interior of the building while producing electricity.

This house from the Solar Decathlon incorporated thin film PV in its windows. *Photo courtesy of Wendy Butler-Burt of the U.S. Department of Energy.*

(left) ❶ Using a template provided by the manufacturer, the crew marks and drills holes for the solar shingle wiring to be pulled through the roof. The holes are under the shingles, but should be caulked or otherwise weather sealed.

(middle two photos) ❷❸ These systems use plastic grommets to line penetrations and a plastic raceway acts as a junction box for the wires. Check with local code officials to ensure these components comply with local code.

(right two photos) ❹❺ In this house there are two strings, with one inverter per string. There is a combiner box on AC side (after the inverters). The photo shows the two AC disconnects, the inverters, and the main panel. The PV wires are hot as soon as the array is installed, so wires from the PV should not be wired into the interior wires until the system is ready to accept the electric current. Systems should be tested prior to final hook up.

All photos courtesy of Decker Homes.

Shingle Systems

Shingle systems are similar to the thin-film laminate product. Shingle systems take advantage of thin film PV and can replace asphalt shingles (Heckeroth and Perkins 2006). This lighter weight plastic replacement for shingles comes in relatively long strips to replace courses of asphalt shingles and reduce the number of electrical connections.

One currently available amorphous asphalt shingle replacement is the Uni-Solar Shingle made by Uni-Solar Ovionics. These PV shingles are applied over a fire-resistant membrane.

Builder Best Practices

Before installing solar equipment, be sure your designs, materials, and construction techniques are as energy efficient as possible. An integrated system design approach, saving at least 30% whole house energy use, should be applied to your homes to ensure the maximum possible value for consumers, and profits for your company. An integrated system design can improve comfort, increase home durability, save money, and improve energy efficiency. Best practices and research reports for energy-efficient construction can be found on www.buildingamerica.gov.

Inviting photovoltaic professionals to join your building team will bring experience and technical capability to help minimize system problems and maximize system performance. Your team will need to include a solar designer, installer, and electrician. Sometimes this can be the same person. Usually the solar designers are also the installers. Often solar design firms also employ master electricians to review their designs. The solar design firm should be familiar with which jurisdictions you'll need permits from, how to contact the local utility for grid-tied systems, and how to get rebate information.

PV installers can be certified by NABCEP (North American Board of Certified Energy Practitioners). Solar energy associations, community colleges, manufacturers, and others offer training. A listing of coursework is available at www.irecusa.org. Ask installation companies what types of training their installers receive and if they plan to pursue NABCEP certification. Find out more about NABCEP at www.nabcep.org/pv_installer.cfm. The NABCEP system installer study guide is a good reference as well as helping installers prepare for the certification test (NABCEP 2003).

Electrical work on the AC side may be done by electricians rather than solar installers (who also may be electricians), or by the solar installers if needed. An electrician is needed for the interconnection to the utility grid.

The design for the system will include the type (BIPV or rack mounted) and number of modules, the size and type of wire, number of inverters, and location of all components. Designers should provide space for wiring runs and for mounting inverters and shut-offs. Make sure the plan has been reviewed by an electrician. You will need good drawings for the local utility, jurisdiction and crew. Locations for the main panel, shut-offs, signage, and the inverter should be clearly indicated on plans. Often these components are mounted on a single board for ease of access.

A photovoltaic firm should know what permits are required. In some jurisdictions only electrical permits are needed. In others, the permit systems can be more complicated. Some jurisdictions give priority attention or reduced fees for projects that include solar features. Because this system will be a grid-tied system, the local utility must approve it. The photovoltaic design firm should know how to get this done.

Choose systems that match your architectural style and are easy to install. Avoid systems that require multiple penetrations through the roof deck or that involve multiple separate arrays. Multiple arrays are possible, but may involve adding more than one inverter.

Standardized design packages with pre-engineered mounting systems and integrated components offer advantages over custom designs. These systems tend to include documentation such as drawings and instructions that aid with permitting and inspections. Pre-engineered systems require less installation time and cost (Dunlop Undated).

Once the PV system has been properly sized and the design has been committed to the plans, ensure that contract documents stipulate the specifications of the equipment and the installation requirements for the installer, including responsibility for quality assurance and corrections. A sample Statement of Work can be found at www.consol.ws/pdf/pv3sow.pdf, and in Appendix I. ConSol, the company that developed this sample Statement of Work, leads a Building America team, and has worked on several ZEH communities using PV and a high level of energy efficiency.

As the roof is being framed, additional structure to support the PV can be installed, but typically should not be needed. Although not needed structurally, backing material may be added to allow for easier installation and more secure lag bolt connections.

Insist that PV installers meet with other trades to work out equipment compatibility, supply, and installations issues. For example:

- Roofers need to know what types of flashing to use, who will be installing it, and when. Roofers also need to know if BIPV will be used that will replace sections of the roof.
- Trades requiring roof penetrations need to know what areas are off limits for vents or other elements that may shade the PV. This coordination issue was the number one area of difficulty identified by PV installers interviewed for this document.
- PV and solar thermal installers need to know what parts of the roof to use for their systems. Typically the truest southern exposure should go to the PV installation.
- For long-term performance, landscape designers and installers need to keep the southern exposure unobstructed from trees and outbuildings.
- Painters and stucco crews need to take all steps necessary to avoid overspray.

SheaHomes offers an example of a well-integrated solar installation. A report on the Scripps Highland project found there "were no issues whatsoever

Home with PV shingle system. *Photo courtesy of Decker Homes.*

Trades requiring roof penetrations need to know what areas are off limits for vents or other elements that may shade the PV. This coordination issue was the number one area of difficulty identified by PV installers interviewed for this document.

regarding roof penetrations (and any leaks as a result of)" at the project. The report notes that the systems were installed with a roof penetration flashing system, the design of which was supported by the roofing company involved in the installation. "That, in all likelihood, made a substantial difference in the success of the project, by engaging the existing roofing subcontractor in the decision-making process, and calling upon the company's expertise in roofing and flashing techniques (Nelson 2005)."

After exterior sheathing is installed, solar mounts and junction boxes may be installed. While on the roof, the solar installer should spray paint the boundaries needed for the PV modules and sections of the roof that should be off limits to other penetrations that may cause shading or that will be blocked by the array.

The best time to install PV modules will depend on the product being used and accommodations worked out with trades. It may be advantageous to wait until after exterior painting. Waiting avoids problems with overspray on solar collector glazing or PV modules.

Production builders should be using a quality assurance process that includes pressurization tests for the house and duct work. Quality assurance should also include the inspection and testing of all solar thermal and PV equipment. Experience has shown that when inspections are done, failure rates on solar thermal systems are very low, much less than 1%. Train your quality inspection staff or sub contractor, or hire a specialty sub-contractor, to test and inspect solar systems. Local utilities may help with this function. Inspection guidance for codes officials (which should be readily adaptable for quality assurance) is available at www.irecusa.org. A detailed testing protocol has been developed by the National Renewable Energy Laboratory and is available at www.nrel.gov/docs/fy03osti/30301.pdf. A quality assurance checklist, developed by ConSol, a team leader for Building America, is available at www.consol.ws/pdf/PV4Checklist.pdf and in Appendix I. Sources for other checklists are listed at the end of the PV Installer Best Practices in the next section.

PV Installer Best Practices

This document does not provide detailed technical best practices for installers. Other references, listed in the Additional Information section can help with details. What this section does do is provide insights into working with production builders.

Work with the builder and his or her designers to draw the PV system into the plans. System location may change with orientation and site access, but putting the system on the plans alerts other subcontractors, site supervisors, and inspectors that the systems are going in. The plans should include predetermined locations for inverters and cut off switches. If needed, the plans should also indicate any structural additions added for easier or stronger installations.

Production building incorporates factory-like processes in the field. It is not uncommon to have houses in various stages of construction as one looks down a street. Depending on the size of the project, it is possible that every trade that supports a particular builder will be represented on the job site every day, but working on different houses. PV installers will need to fit into this rhythm. It may be necessary to schedule crews to do pre-installations, array installations, and interior component installations. Different crews may do these tasks simultaneously, or one crew may have different jobs at different times. Be clear with the site supervisor about demands for crew time.

Work with site supervisors, roofers, plumbers, and others to determine the best points in time to be in a house and what materials to provide. Pay attention to other trades that will be working in the same spaces.

- Spray paint roof areas before the finish roof is installed that need to be protected for mounting modules and to maintain solar exposure.
- If arrays go in before house painting is complete, cover them with plastic to protect against overspray. Wind may carry overspray from nearby houses so check the status of painting on neighboring houses. Remove the plastic when painting is complete or ensure that somebody has that responsibility.

- Work with the builder or designer to establish wire runs in plans to avoid conflicts. Also add to the plans any structural changes that are needed for mounting.

As noted, the area to be used for the PV array should be outlined on the roof deck, before finish roofing is installed, with orange paint. The solar designer should walk the edges of the PV array location—especially the corners—with the "Solar Pathfinder" or other shade analysis device to make sure there are no obstructions during the critical solar window (9am – 3pm) before applying paint on the deck. The painted area should extend to the south beyond the actual PV footprint to avoid the installation of any components (vents or stacks) that may cast a shadow on the array. Plumbers, electricians, roofers, vent installers, and any other relevant trades should be informed that the outlined area is off limits to penetrations.

If stand-offs are needed for a rack mounted system, they should be installed and flashed before the final roofing material is installed.

If part of the roofing material is BIPV, the base roofing felt or other membrane material should be installed first. The BIPV can then be installed and final wiring done. There may be minor finish work edging the BIPV.

Rack mounted systems require roofing to be completed before installing the system. Installers can compensate with plastic wedges for modules that are slightly out of square and roofs that aren't perfectly flat.

Each row of modules should be tested as arrays are installed to isolate any loose connections, ground faults, or faulty modules.

Cover the installed PV arrays with tarps or drop cloths during external painting of the house. Check the status of nearby house painting. Wind can carry overspray from a neighboring house. Overspray on the modules can greatly reduce their power generation.

Provide quality assurance inspections. Work with the site supervisor. Learn from the inspections to improve future work. Have the electrician do a commissioning check before the last connection is made (between the PV and the DC breaker). Inspection guidance for codes officials (which should be readily adaptable for quality assurance) is available at www.irecusa.org (Brooks Engineering 2006) and at the Southwest Technology Development Institute at www.nmsu.edu/ntdi (Wiles 2006a and b). An onsite commissioning process has been published by the National Renewable Energy Laboratory (Barker and Norton 2003). A quality assurance checklist developed by ConSol, a team leader for Building America, is available at www.consol.ws/pdf/PV4Checklist.pdf and in Appendix I. A checklist designed specifically for compliance with the NEC has been developed by John Wiles (2006).

Gather a homeowner packet of information, including homeowner/installation guides from the PV manufacturer, the inverter manufacturer and from any monitoring systems that have been installed. Make this information part of the builder's homeowners manual.

An evaluation of Florida experience suggests a number of reliability problems can be attributed to the quality of installation and workmanship of contractors, primarily due to the limited workforce and experience. Often these problems can be attributed to the lack of good plans, drawings and instructions for the installation. In other cases, the limited knowledge, skills and experience among contractors have resulted in poor quality installations (Dunlop undated, and Wiles, Brooks, and Schultze 2006). The following table lists a set of measures that field inspectors have found to be problem areas.

THE ***WRONG*** WAY | THE ***RIGHT*** WAY

Always confirm that solar exposure is unobstructed. Shading is a critical flaw in installation.

(left) Photo courtesy of NREL. (right) Photo courtesy of Heidi Stewart of PNNL.

Roof penetrations must be properly flashed and sealed.

Photos courtesy of Namaste Solar Electric

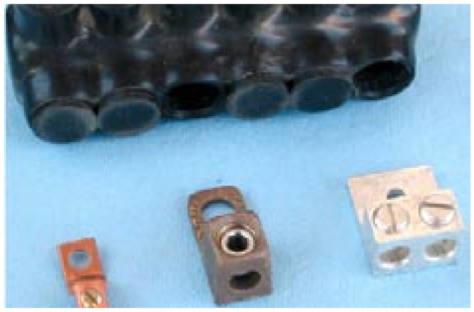
Wire connections must be properly installed. New “plug-and-play” wires systems help solve this problem.

(left) Photo courtesy of John Wiles of SWTDI. (right) Photo courtesy of Kurt Johnson of SunPower

Electrical materials (lugs, screws, wires) selection is critical for a safe and durable system. In the picture to the left, indoor rated materials were used for an outdoor grounding application.

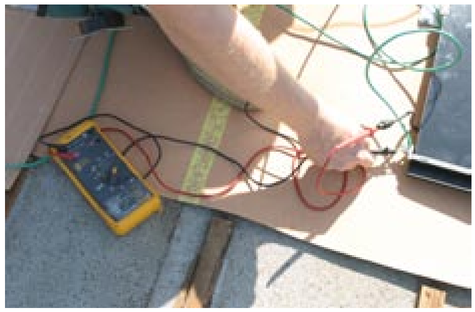
(left) Photo courtesy of John Wiles of SWTDI

THE ***WRONG*** WAY | THE ***RIGHT*** WAY

Materials must be properly installed. Wires must fit lugs. Use lugs listed for proper environment.

Photos courtesy of John Wiles of SWTDI.

Testing as arrays are installed allows for isolating problem panels and troubleshooting the overall system. A non-functioning array might as well be constantly facing the night sky.

(left) Photo courtesy of NASA. (right) Photo courtesy of Kurt Johnson of SunPower.


Service providers must be able to disconnect each piece of serviceable equipment in the PV system, such as arrays and inverters. In simple grid tied systems there will be a DC disconnect between the modules and the inverters and an AC disconnect between the inverters and the panel. Components need to be placed in readily accessible locations.

(left) Photo courtesy of John Wiles of SWTDI.


Arrays must be protected from construction activities, including paint overspray.

(right) Photo courtesy of NREL.

Long Term Maintenance

PV systems have very simple long term maintenance. These systems should last at least 20 years. Here are the basic steps homeowners need to follow:

- Yearly cleaning of the PV modules or rely on seasonal rain,
- Occasional snow removal – depending on the climate (do not use metal objects to clean glass),
- If any wires are exposed, yearly checking for evidence of hungry critters (like squirrels), and
- Maintaining a performance log to watch for major variations in energy production (non-weather related) to track potential problems. Systems that include web-based monitoring can provide this service.

Resources and References

California Energy Commission (CEC) lists of Eligible Equipment
www.consumerenergycenter.org/erprebate/equipment.html

NABCEP – North American Board of Certified Energy Practitioners
www.nabcep.org

IREC – Interstate Renewable Energy Council
www.irecusa.org

Southwest Technology Development Institute, New Mexico State University
www.nmsu.edu/~tdi/

SEI – Solar Energy International
www.solarenergy.org

Namaste Solar Electric
www.namastesolar.com

FSEC – Florida Solar Energy Center
www.fsec.ucf.edu

NREL – National Renewable Energy Laboratory, Solar Research
www.nrel.gov/solar/

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Wiles, John. 2005. *Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices*. SAND-2005-0342-N, Prepared for Sandia National Laboratories by the Southwest Technology Development Institute at New Mexico State University, Las Cruces, New Mexico. (electronic version was published in 2006) www.nmsu.edu/~tdi/